DC Community Microgrid: Smart Affordable DC Electricity for an Underserved Inner City Community

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Low Voltage DC Microgrids

- Advantages
  - Eliminate the cost and extra losses of redundant AC-DC conversions
  - Lower Cost implementation of DER than AC microgrids
  - Lower installation, infrastructure and maintenance cost of new microgrids
- Opportunities
  - Green Buildings, Data Centers
  - Community Microgrid
  - Multiple Inter-connected Microgrids within a City
- Challenges
  - Lack of standards
  - Distribution and Protection!

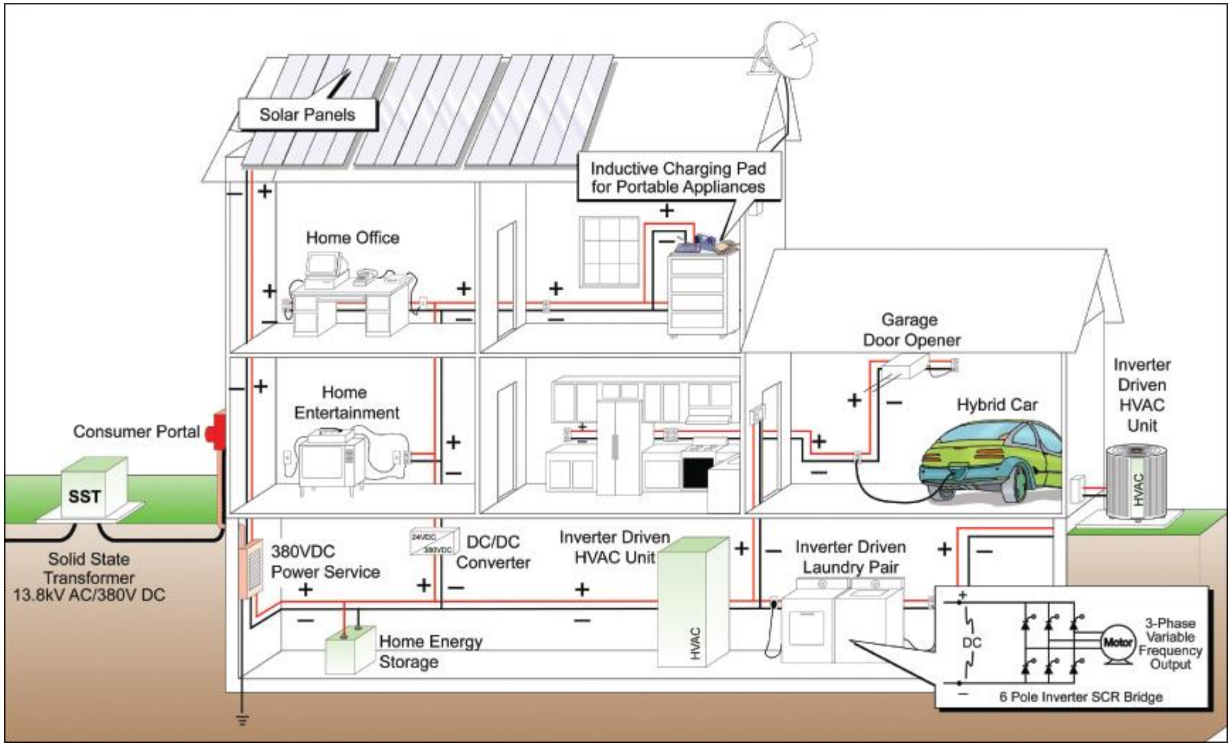
LVDC Microgrid Value Proposition

- DC Microgrids will accelerate the adoption and insertion of power electronics into the electric grid by enabling effective utilization of energy saving loads and integration between renewable energy resources and storage
  - More efficient power delivery and more effective energy dispatch
  - *DC systems will be less complex and less expensive to deploy, operate and maintain.*
  - Growing "DC Backbone" of building and home loads (lighting, motors, electronics)
  - No need for phase synchronization
  - Plug and play power electronics enabled systems can be achieved
  - DC systems can be safer than AC

    Control of ARC flash exposure can be realized

    →*Faster Protection is a key element*
- *Circuit protection can be faster and more reliable→New ideas for protective devices and distribution are needed!*

The DC-Enabled Home



The "Smart Home" concept requires that a home be converted to DC distribution in order to enable:

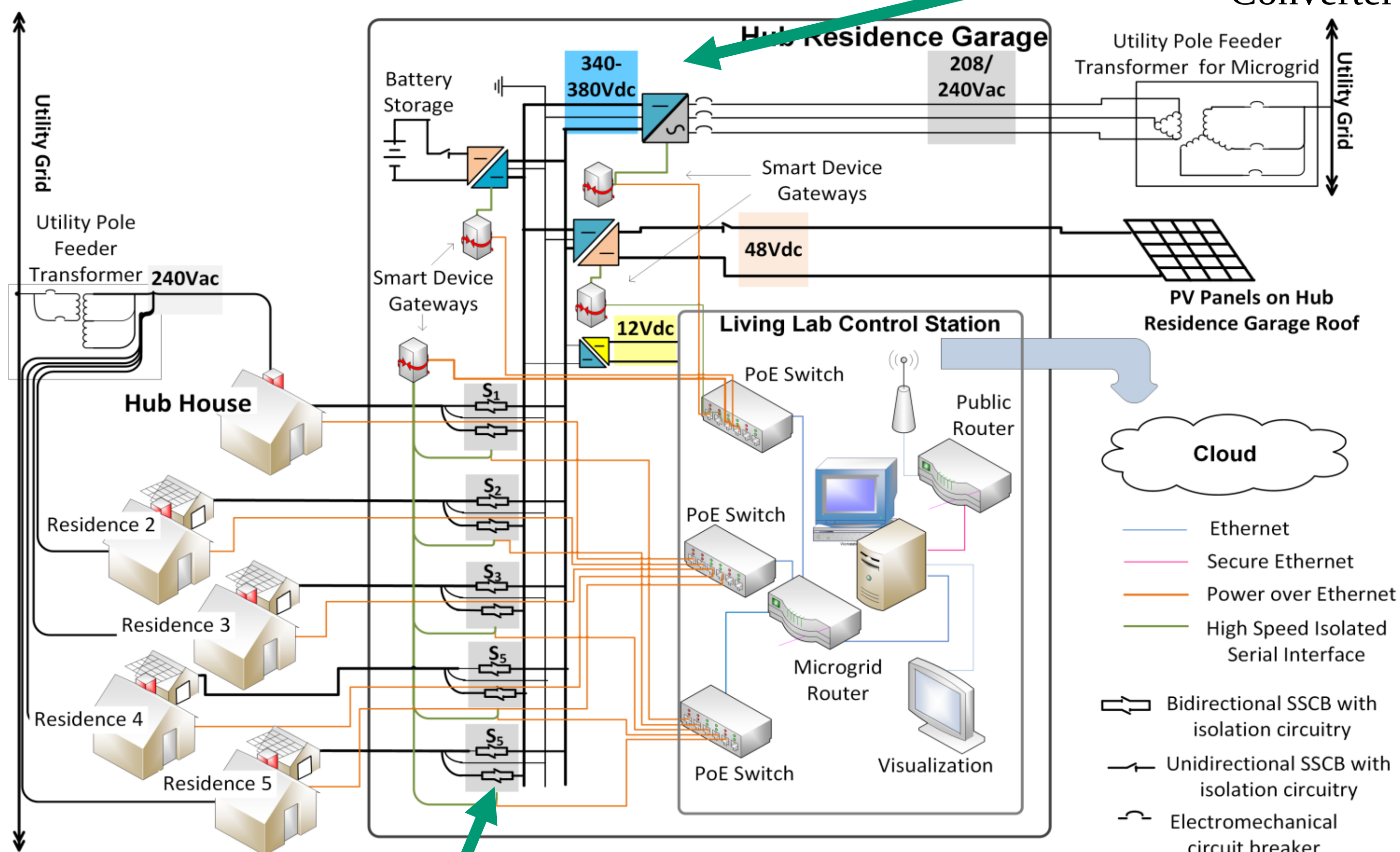
- Efficient power delivery to growing number of DC loads
- Cost effective integration of renewable energy and energy storage

Community DC Microgrid Project

- Low income households expend >14% on utilities compared to middle class households, which expend 3% of their income
- Utility costs are a major impediment to economic mobility—this fact is recently becoming recognized
- Adoption of cost saving/environmentally friendly technologies such as Solar PV plus batteries is out of reach of low income households—creates an ever widening disparity gap
- Proposed Solution: Interconnected smart homes with cooperative energy

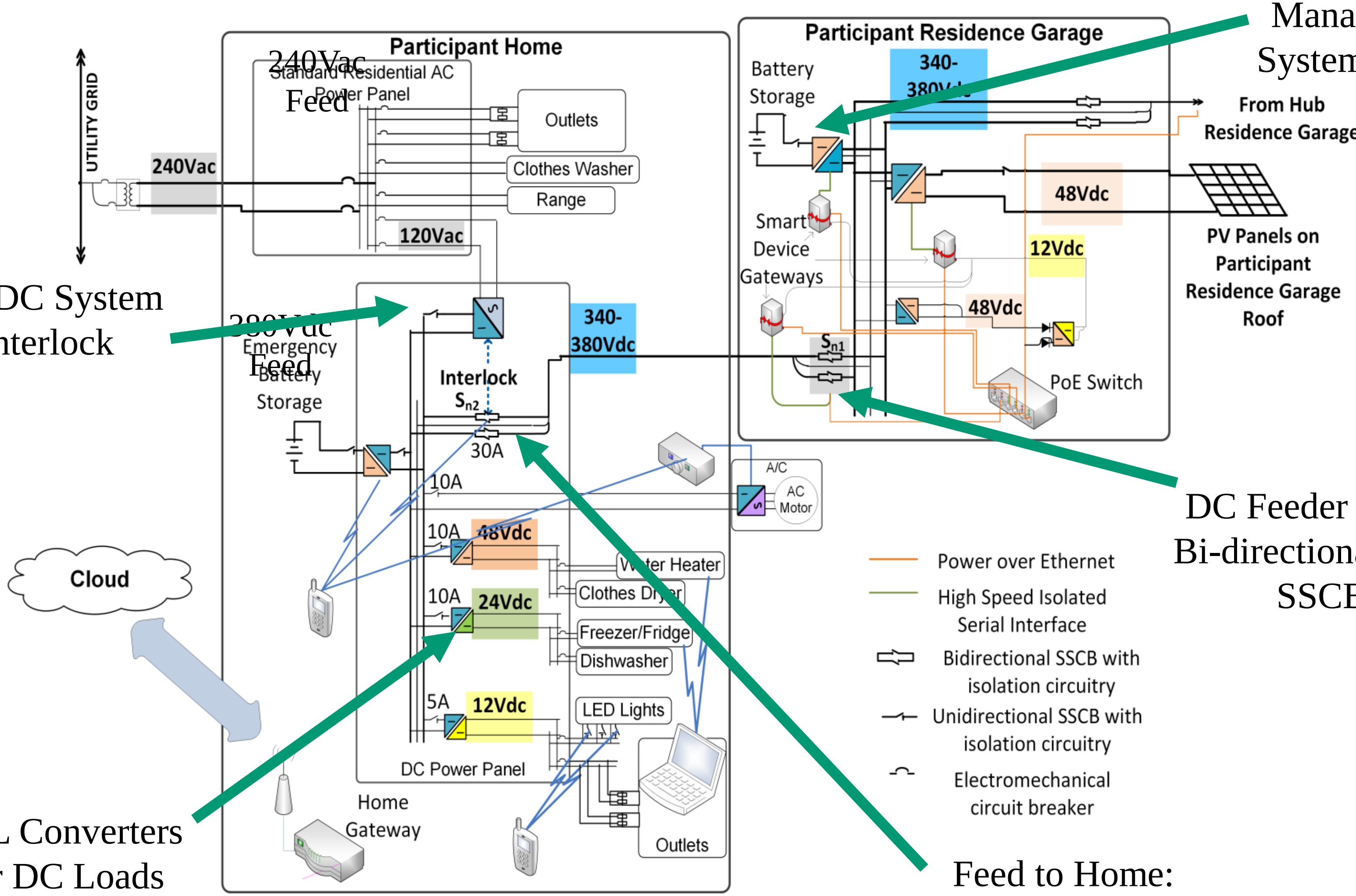
Distribution System Design—
Lead Home Garage (Sub-Station)

Bi-directional AC-DC Converter



Feeds to CMG Homes:
Bi-directional Solid State Circuit Breakers (SSCBs)

Distribution System Design—Home



Battery Management System (BMS)

AC/DC System Interlock

DC Feeder Home: Bi-directional Solid SSCB

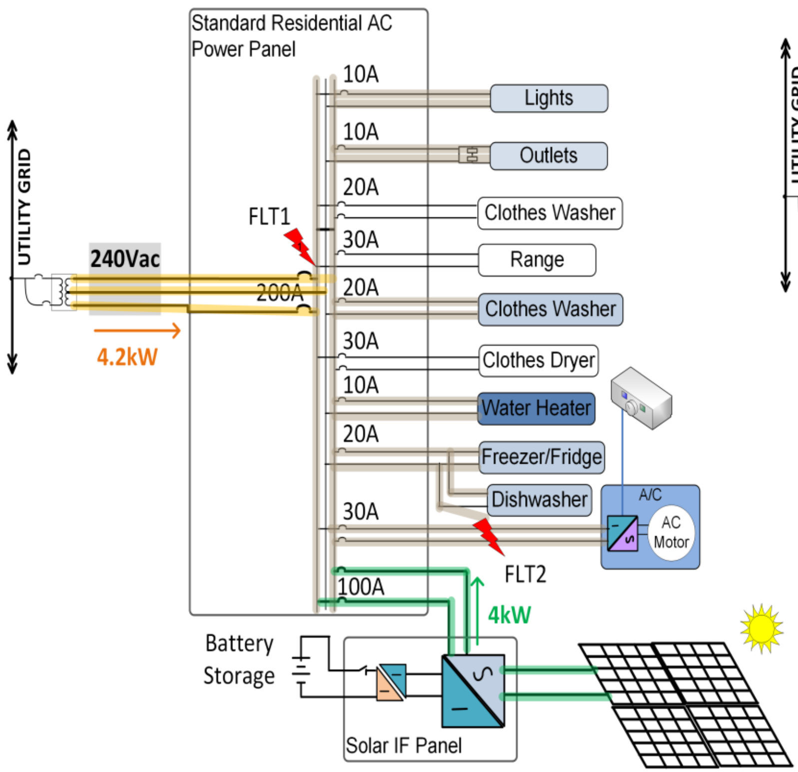
POL Converters for DC Loads

Feed to Home: Uni-directional SSCBs

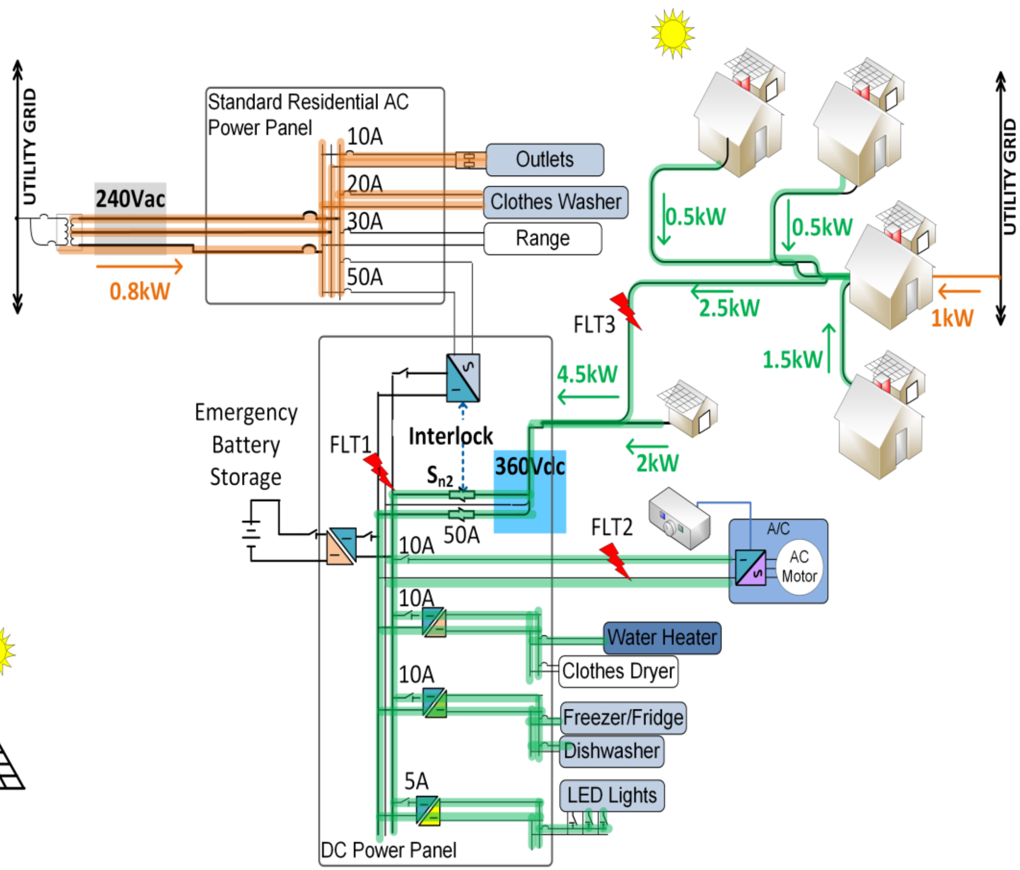
AC vs. DC Home Load Break-Outs

Load	*AC Service Voltage*	*DC Service Voltage*	*AC Load Power Consumption (kW)*	*DC Load Power Consumption (kW)*	*Usage per Month (Hr)*	*AC Monthly KW-Hr*	*DC Monthly KW-Hr*	*AC Appliance Cost*	*DC Appliance Cost*
A/C	230	360	2.0	0.9	360	720	324	$ 5,212.00	$ 10,000.00
Range	230	N/A	5.0	N/A	100	500	N/A	$ 1,072.00	N/A
Water Heater	230	48	3.5	0.6	120	420	72	$ 1,100.00	$ 1,350.00
Dryer	230	48	5.0	2.5	20	100	50	$ 600.00	$ 1,250.00
Washer	115	N/A	0.5	N/A	10	5	N/A	$ 1,000.00	N/A
Furnace	115	N/A	0.5	N/A	0	0	N/A	$ 2,370.00	N/A
Dishwasher	115	24	1.3	0.6	10	13	6	$ 350.00	$ 700.00
Refrigerator	115	24	0.5	0.3	150	75	37.5	$ 1,100.00	$ 1,400.00
Freezer	115	24	0.4	0.2	60	21	12		
Microwave	115	12	1.0	0.8	10	10	8	$ 100.00	$ 500.00
Electronic Loads	115	12	0.50	0.20	113	56	23	$ 1,000.00	$ 1,200.00
Lighting	115	12	0.8	0.1	100	40	10	$ 1,770.00	$ 2,500.00
Ceiling Fans	115	12	0.3	0.2	360	108	72	$ 800.00	$ 1,500.00

AC vs. DC Home Solar/Battery Integration

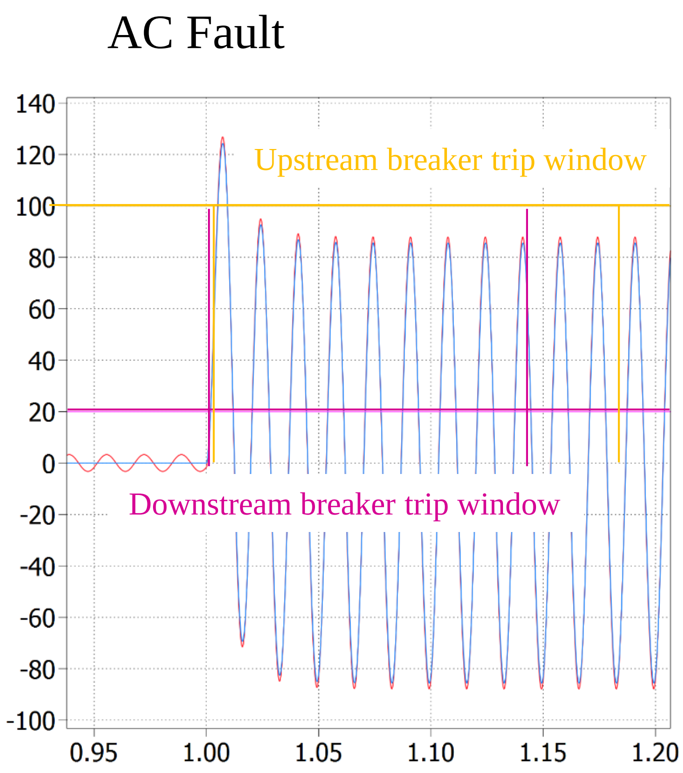


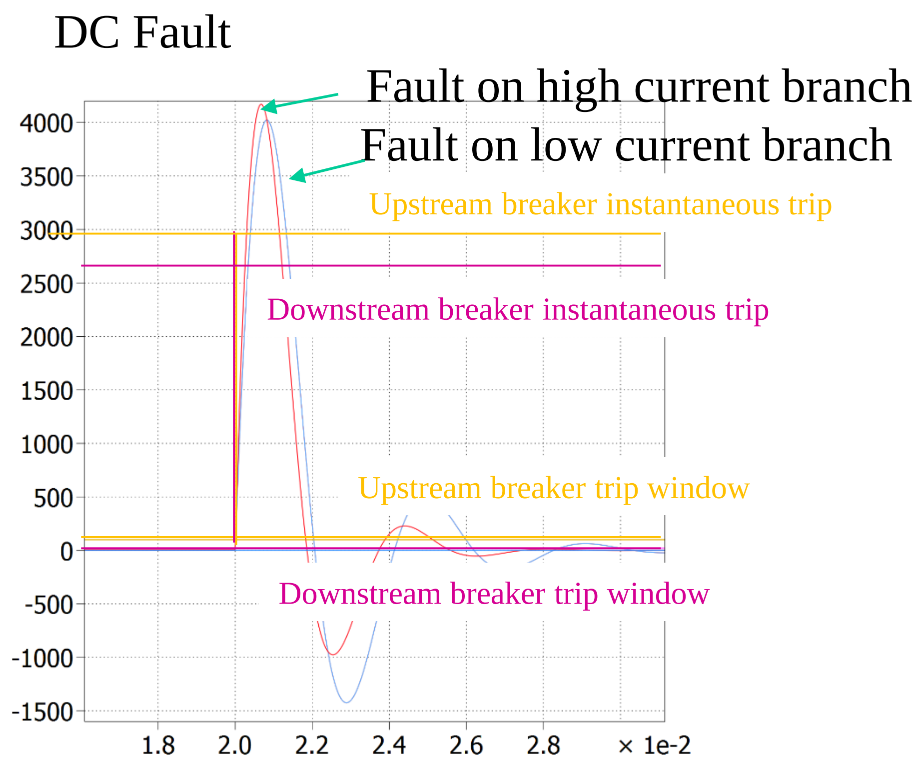
AC wired home with installed solar panels



Proposed DC microgrid with mixed AC and DC wired home

What is the issue with DC Protection?

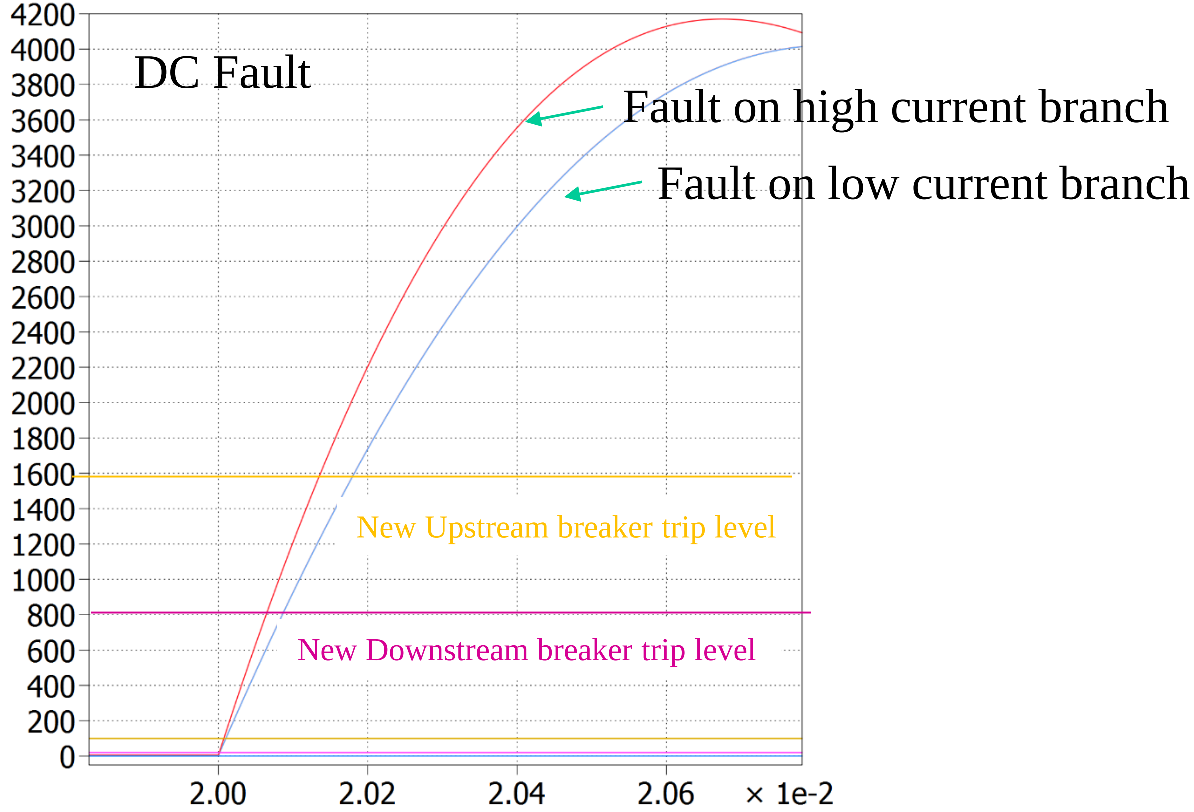




AC System: Zero crossing provides opportunity for electromechanical circuit breaker arc to extinguish. Upstream & downstream circuit breakers can coordinate because AC reactance limits currents

DC System: No zero crossing, so electromechanical circuit breakers must be de-rated. Virtually impossible for upstream & downstream circuit breakers to coordinate due to current limitation of upstream source

Why Solid State Circuit Breaker?



Circuit breaker needs to act within the first few microseconds

For Radial Systems: Need to distinguish between upstream and downstream faults in order isolate the fault to the closest location

For Ring Buses: High speed communications, high degree of sensing and embedded intelligence are required in order to isolate the fault to the closest location

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DC System Circuit Breaker Coordination

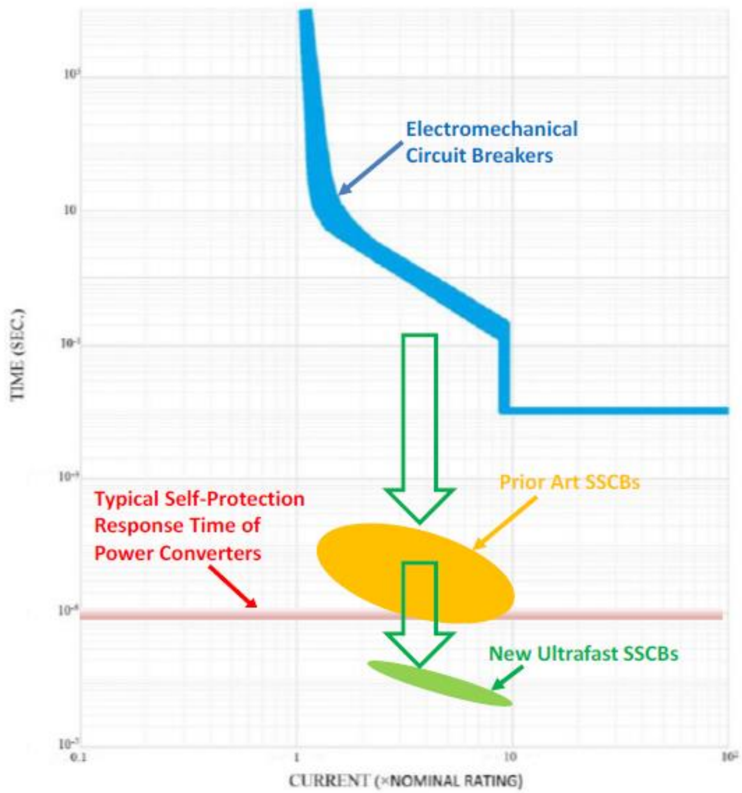


Fig. 1. Current and reaction time curves of traditional electromechanical circuit breakers, prior art SSCBs, and the proposed SSCB concept.

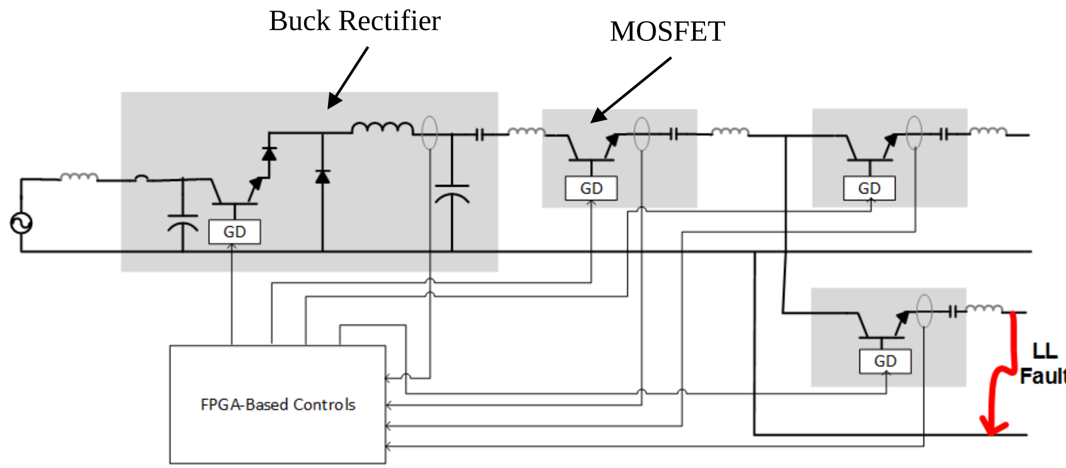
The Fault is Characterized by the system capacitance and cable inductance, so the device must be able to act very quickly on the LC ring-up

Impact of Wide Band Gap Devices on Protection

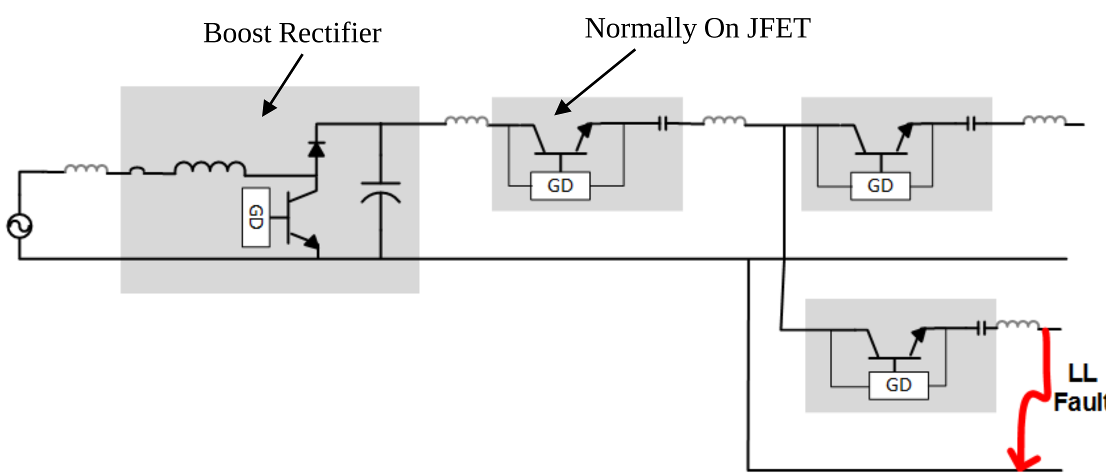
- Low conduction losses
- High commutation speed
- Devices suitable for HVDC but they are too costly right now
- The cost issue may be manageable for highly integrated MVDC systems (i.e. Navy shipboard)
- The current ratings are too low for MVDC (module paralleling is required)
- SiC and GaN JFET are attractive for LVDC

DC Circuit Breaker Solutions

Communications Based



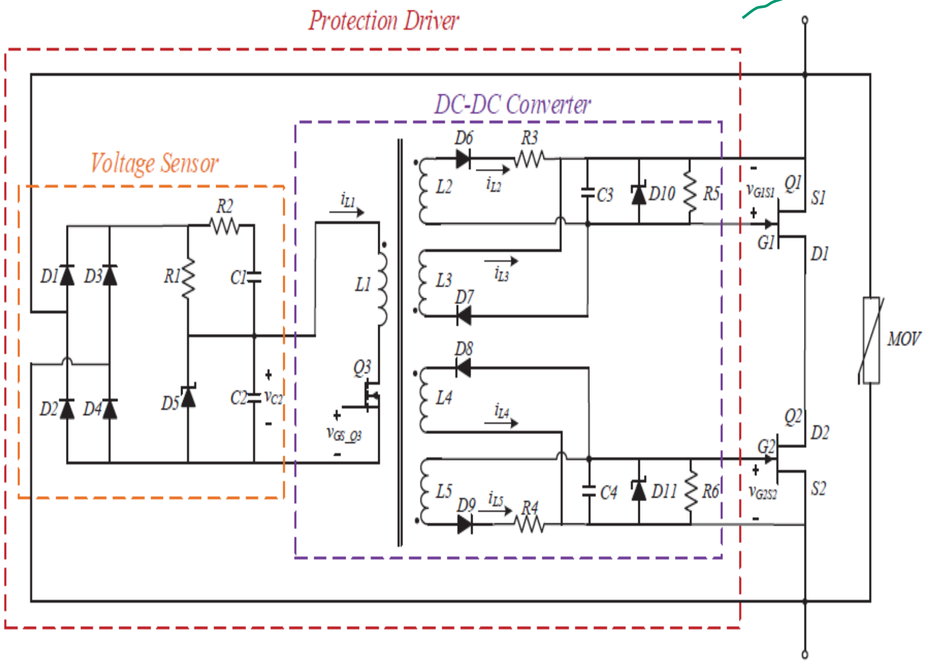
Autonomous

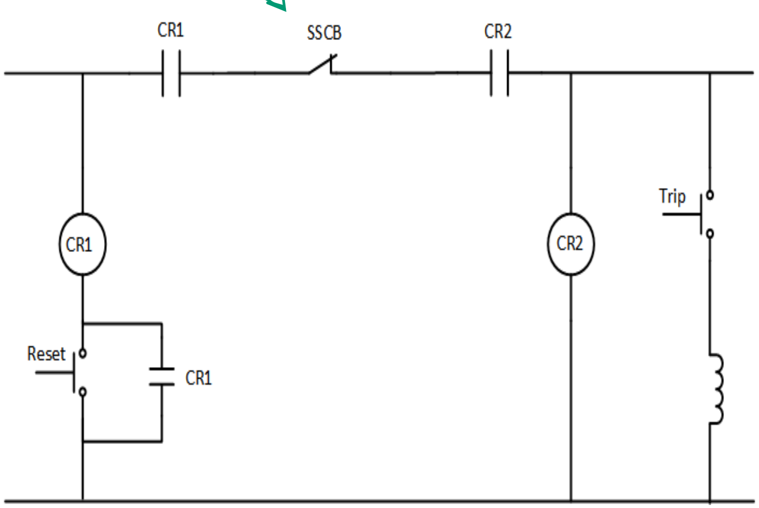


Normal "On" SiC JFET Based Approach

This concept will be tested, developed and evolved

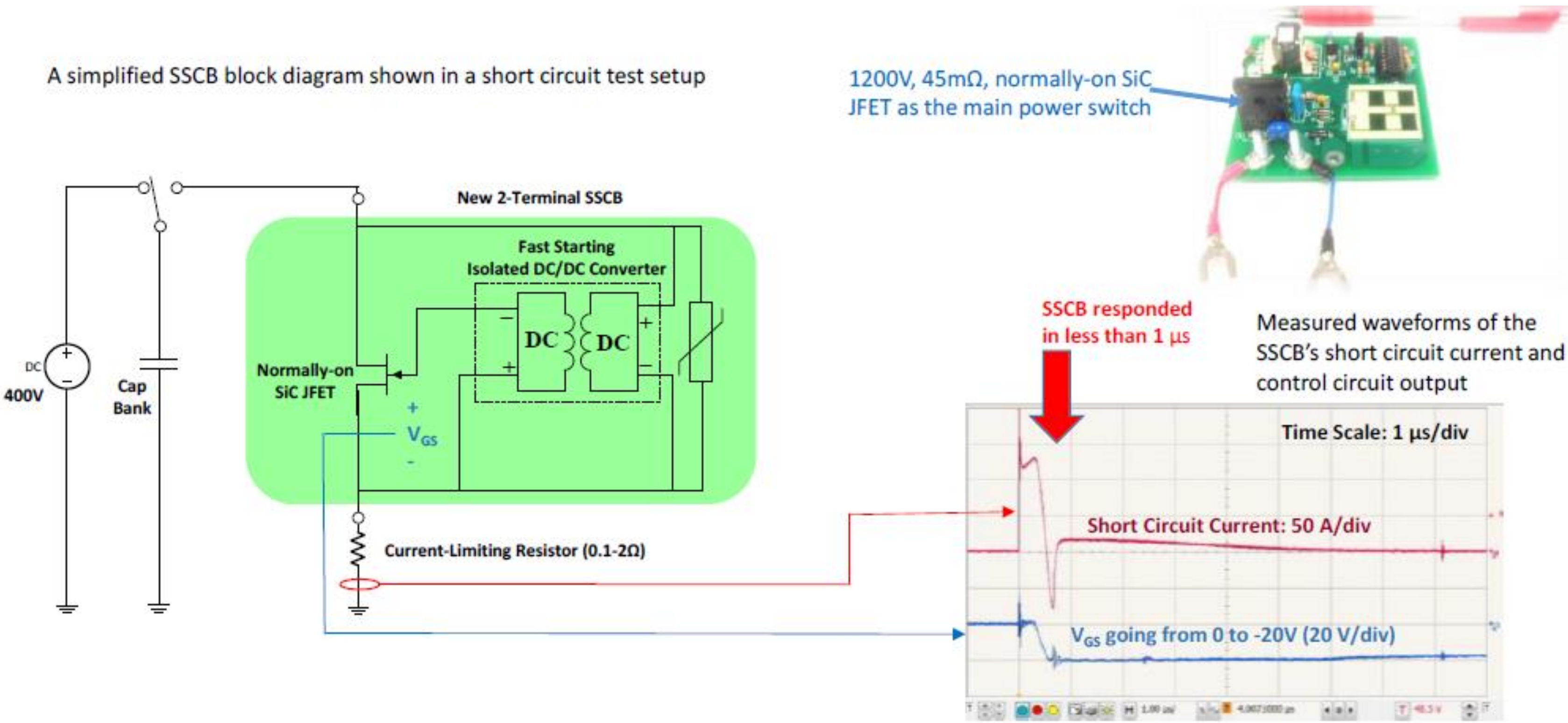
Bi-Directional Implementation





- Suitable for 400V-1000V applications
- Level trip setting through a simple resistor adjustment
- Simple relay circuit for fault isolation

JFET Based Switch Implementation & Test



Collaboration with Illinois Institute of Technology

Broader Vision

- Increase adoption of renewable energy among a greater population within the U.S. building upon concepts developed in India and Taiwan
- Protective concepts are applicable to DC buildings
- Enables viable DC system implementations → *Commercialization of DC SSCB*
- *Leads to first embedded urban Community Microgrid*—potential for significant social impact, addresses the educational impediment to adoption